TREND ANALYSIS IN ASSESMENT AND PREDICTION OF SLOPE STABILITY IN OPEN COAL MINES

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ABSTRACT

Geotechnical *analysis of the condition of slope stability of excavation blocks in the open coal mine allows to define the safety assessment and prediction of the ongoing process of exploration and planning in future development.*
Subject of research in this paper will be geotechnical analyze of working environment covered with everyday exploitation and already completed benches.
In this paper will be performed comprehensive analysis of several distinctive sections. We used the information from monthly reports of geotechnical stability of excavated blocks in the period from April 2009 to December 2010.
The primary goals of the research area is a function of calculating, assessing, analyzing and prediction the geotechnical stability of final slopes of the coal open pit mine.
Accordingly, the goals of the research in this paper, in accordance with the basic task of main plane of the coal mine, will be:
- Determination of the coefficient of stability;
- Assessment of the stability of excavation blocks;
- Analysis of the slope stability of working and final benches;
- Trend analysis and prediction of assessing the slope stability and
- Conclusion and suggestion for further research

1. INTRODUCTION

In the first half of 2008 in the coal mine Suvodol - Macedonia, there was critical condition regarding coal deposit moved about 1 cm per day from the Southeast to Northwest so this situation threatens directly the stability of slopes of the blocks, in the process of exploitation.

Changing of the physical - mechanical properties of rock masses is a very common cause of instability slope. Changing the level of groundwater, their freezing and thawing, also creates new conditions in the voltage state of the rock mass and leads to the emergence of instability slope. Long process of change in voltage condition and form of deformation, at the other on equal terms in which it is rock mass, can lead to instability of the slope.

At the same time, in certain parts of the occurs of rock mass overload and deformations that reduce the stability of the slope. The process of releasing the voltage near new made slope, cause a new discontinuity and weakening of the rock mass.

The condition for stability of any slope is a balance between external forces and internal resistance of the middle of the slope.

Continued analysis of geotechnical condition of stability of the slopes of the blocks in the mine, "Suvodol" allow chance for the assessment safety of the ongoing process of exploration and planning of the development in future.

Some of the major factors for assessing the stability of slopes are physical - mechanical properties of rock masses. Any change in the level of groundwater, i.e. their freezing and thawing and etc., creates new conditions in the voltage state of the rock mass and leads to the emergence of unstable slope. To solve this situation needed further analysis of the stability of the pit and also concrete work plans of the systems in Suvodol mine and very carefully monitoring of the situation on the ground and monitoring of the system of cracks that had occurred in that period. In this paper is analyzed only a small fraction of all events, activities, decisions and steps taken in that period in the Suvodol mine.

Special emphasis is given to the possibility of planning the future development of the mine in order to achieve the required minimum safety for performance of mining operations.

The primary goals of the research are in function of calculating, assessing and analyzing of the geotechnical stability of working and final slopes of the open pit “Suvodol”.

Specifically, the objectives of the research are consistent with the basic task of the monthly analysis, and they are:

- section of analysis for the past year,
- analysis and review of the results,
- assessment of the actions taken by management on open coal mine “Suvodol”,
- review of achieved results.

Methodology of research, mainly include research from the field and macroscopic assessment of the geotechnical stability of the pit and blocks, and with mathematical analysis and application of modern methods with equilibrium limit are analyzed geotechnical stability of the slopes of open pit.

In analyzing were used modern methods to define the stability of slopes. When it was selected most characteristic methods in this area, for example: ordinary method, the method of Bishop, the method of Spencer and the method of Janbu.

2. GEOMECHANICAL PARAMETERS USED IN ANALYSIS OF STABILITY

To get the most relevant and most characteristics results from the analysis of stability, the most important was to make the right choices and precise values of geomechanical parameters of materials were surveyed. Therefore, while solving this problem, were used all data by both current from previous investigations and trials, and geomechanical parameters adopted are shown in Table 1.

Table 1. Table of geomehanical parametars of the material

No.	Type of material	Geomechanical sign	γ (kN/m^3)	φ (°)	c (kN/m^2)
1	Quaternary deluvial sediments	CL/CI	19	21	10
2	Tripoli	TR	15,64	17,90	31,83
2*	Tripoli - perturbed	TR	15,64	13,00	0
3	Coal	L	11,61	30,00	45,00
3*	Coal - perturbed	L	11,61	30,00	0
4	Coal clay	OH/OI	16,63	10,27	0
5	Floor sands and dust	SFs SFs/MI	21,2	20,77	0
5*	Perturbed material	SFs SFs/MI	19.5	10,60	0
6	Gneiss	Gn	22	50	200
7	Gravel material from break mother rock	SW/Gn	21,60	20,00	0
8	Mica dust	MI/MH	15,45	12,76	0

In some parts of the open pit there are zones with structural-tectonic disturbances particularly in tripoli, as manifested, often through vertical cracks with variable length and they appear between two slopes.

When is analyzing the stability of tripoli in these circumstances are taken data from tests on shear strength of longitudinal discontinuities c=0 (kN/m^2) and $\varphi = 13^0$.

Based on data from the current excavation of the tripoli as more specific areas of disturbance are separated contacts from the tripoli with coal and Quarternary roof sediments and margins of the open pit.

On the Micro location 6 is identified set of mica dust in tripoli (for what is believed that is been intercalated with the activity of the fossil landslide) and it received very low sturdiness parameters and this further complicates the stability of this field.

In unspoiled parties of the tripoli in Micro location 6 and Micro location 7 were made three measuring points on which the measured elements of the collapse of the layered of the slates and result shows that the layers have mild declines from 5% to 11%.

This almost horizontal downs affect to favorable stability of the entire mine, although the collapse at the layers is the Erosive Basic (lowest zone of excavation). Namely, it is very small and does not cause significant destabilization.

As can be seen (from Table 1) there are some affected parties in the coal seam that is also associated with fossil landslide, so the analysis of stability in this part of cohesiveness is considered equal to zero.

As already mentioned, the underground sediments almost entirely are water saturated and incoherent, as that the spoiled, and in fresh material cohesion is zero and they are different by strength only by the angle of internal friction that is higher in double in unspoiled parties.

Gneisses is the most common rocks (kristalyne) which is extends in the entire series, and it is best seen on the edges of the basin, while grus-like (detrital waste) is a material that is made from the floor sands and gravel, and occurs over the basic rock.

Finally it should be noted and the impact of hydrogeological condition as a significant factor for the stability of slopes.

In zones where this condition is well defined and is real displayed as a parameter in the analysis of Sections, output results are very concrete.

Perhaps research in this area in future should be directed to the observation of the changes in this parameter, during the dry and rainy periods, ie depending on whether they are affecting different parameters during the analysis of stability.

3. ANALYSIS OF GEOTECHNICAL STABILITY OF WORKING SLOPES

Analysis of geotehnichical stability of working slopes in the open pit "Suvodol" from April 2009. is taken from monthly reports that analyze the characteristic sections that are selected as most critical for a particular month, in line with planned monthly activities in the open pit " Suvodol".

Selected sections are different for each month toward the whole mine or, specifically, according to plan of work in open pit mine is choose the most characteristic sections for the period.

The basic aim of this paper is to make a complete analysis of data gated for the stability of slopes in the period from April 2009 to April 2010 and to assess the stability of the open pit mine, ie to identify some of the measures and procedures to stabilize the working slopes.

In the period being studied were made twelve reports where they were analyzed sixty transverse and longitudinal sections which were characteristic for the particular month so that certain sections are repeated several times.

Based on these data is made analysis of the results according to which graphical and tabular display of the determined sections to recognize the trend of coefficient of stability in different months for the same sections. For the analysis were selected sections: P08 - P08', P09 - P09', P10 - 10', 49-49', 53-53', 55-55', 72-72' and 76-76'.

In addition, there are information about the two most distinctive section.

Section P08-P08'

Section P08 - P08' is analyzed in April, July, August and September 2009. and obtained the results shown in Table 2. These results from (section P08 - P08', Figure 1) show that the section is beginning to stabilize and from the minimum coefficient of stability from 0.759 in April 2009 is increased to 1.155 in September 2009.

Table 2. Results from the analysis of section P08 - P08'

Method	April 2009	July 2009	August 2009	September 2009
Ordinary	0,759	0,759	0,765	1,155
Bishop	0,935	0,935	0,941	1,225
Janbu	0,871	0,871	0,865	1,192
Spencer	0,935	0,935	0,954	1,261

That is below the limit of reliability coefficient of 1.3, but shows that your account is suspended under stability, so you need to take measures and actions to stabilize the coefficient of reliability. The Graph 1 shows the movement of ratio analysis in four months.

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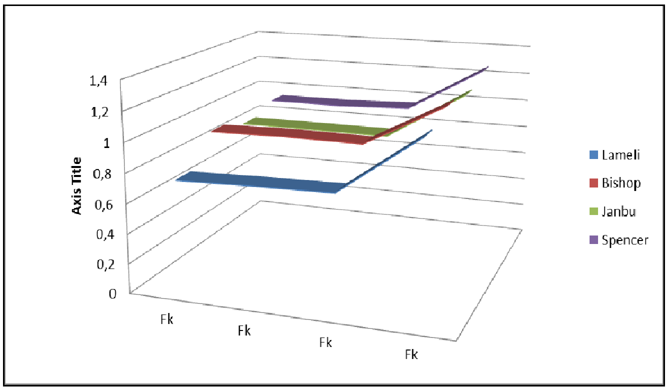

Figure 1 Factor of Safety on Section P08-P08’

Section 49-49'

Section 49-49' is most analyzed primarily for the specific position, ie It covers the mass in the mine were excavate last year and where was concentrated the basic machinery for excavation of waste.

This section is analyzed in eight months in the period of research, in April, May, June, July, August, October 2009 and January and February in 2010. Because this section was analyzed over a long time of period is concentrated excavation of waste that is the best indicator of movement of the slope stability in the open pit mine “Suvodol”.

In the table 3 is given a tabular display of movements of the minimum coefficient of stability that is from 0.935 in April 2009 to 1.269 in October 2009, so it is seen that the stability of this section is suspended and moves within the allowed parameters.

Table 3. Input table from Geotechnical analyses

Method	April 2009	May 2009	June 2009	July 2009	August 2009	October 2009	January 2010	February 2010
Ordinary	0.935	1.107	1.069	0.935	1.003	1.269	0.997	1.253
Bishop	1.069	1.270	1.347	1.069	1.069	1.392	1.194	1.346
Janbu	0.928	1.220	1.199	0.928	1.002	1.214	1.063	1.249
Spencer	1.105	1.290	1.359	1.105	1.105	1.422	1.208	1.362

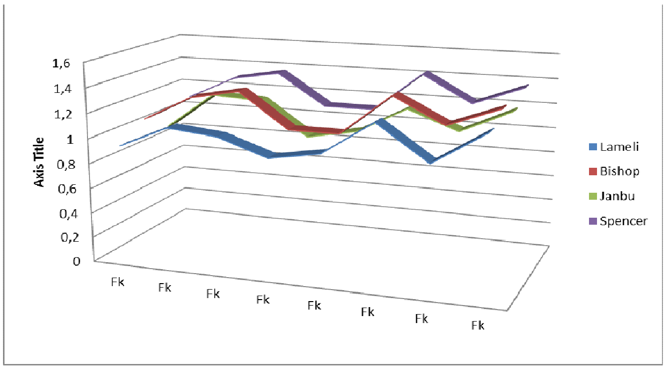

Figure 2. Factor of Safety for section 49 – 49’

Figure 3. Real view of section 49 – 49’

3.1. Trend Analysis

Considering the time interval and frequency of analysis data of the section 49-49', it is detail treated using the trend analysis for development planning and the dynamics of exploitation of coal mine "Suvodol".

Trend analysis was performed according to the following 5 actions:

1. choice of regression analysis;
2. establish the analytical dependence and the value of R2 separately for each regression analysis;
3. ranking of obtained analytical dependencies according to the value of R2;
4. calculation of values for y = f (x) for values of x from 4 to 19;
5. analyzing the values of x from 15 to 19, with step 1

In continue is given the explanation separately for each procedure.

3.1.1. Choice of regression analysis

Taking the nature of the discrete function Fs = f (x), the number of data, the defined area of function (D.O. Є N = {4, 5, …, 19}) value of the function (V_f Є R = {0.0, …, 2.0}), as the most appropriate regression analysis for trend analysis to assess the stability of slopes of blocks were adopted:

– linear, y = ax + b;
– polynomial from 2 degree, $y = ax^2 + bx + c$;
– polynomial from 3 degree, $y = ax^3 + bx^2 + cx + d$;
– logarithmic, y = a ln (x) + b.

Determining the analytical dependence and the value of R2 separately for each regression analysis. According to the analysis made in MS Excel, obtained the following analytical expressions for regression analysis (Table 4).

3.1.2. Janbu method

Table 4. Formulas derived by a Jambu for section 49 – 49’

No.	Regression analysis	Formula	R^2	Status
1	linear	y=0.0132x+0.9899	0,1260	3
2	polynomial from 2 degree	$y=0.0009x^2-0.0029x+1.0527$	0,1301	2
3	polynomial from 3 degree	$y=0.0013x^3-0.0338x^2+0.277x+0.3675$	0,1812	1
4	logarithmic	y=0.1068ln(x)+0.8825	0,1223	4

3.1.3. Rating of obtained analytical dependencies according to the value of R^2

According to the ranking in Table 4, we get the conclusion that polynomial from 3 degree (cubic) regression analysis has the maximum value for R^2, or R^2 = 0.1812. Although this value is very low (R^2 <0.3), can not conclude a "more" analytical dependence between the projected factor of safety and time.

However, this regression analysis is adopted as a trend analysis to assess the stability of slopes of the blocks of this section.

3.1.4. Calculation of values for y=f(x)

Based on analytical expressions for regression analysis was done calculating of the values for y = f (x) for values of x 4 to 19. After that is received data given in Table 4 and from them is made Figure 4.

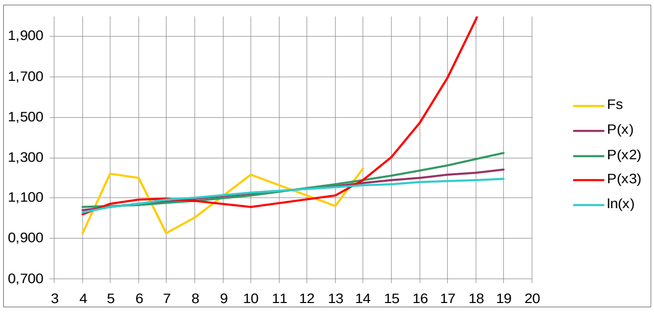

Figure 4. Graphic view by method of Jambu for section 49 – 49’

3.1.5. Analyzing the Values

According to the diagram of the Figure 1, and according to data from Table 5, can ascertain the following conclusions:

- three regression analysis have the same trend of slight increase, but only is different polynomial regression analysis from 3 degrees has a faster increasing trend, especially in the last two months of research, ie June and July in 2010,
- polynomial from 3 degree (cubic) regression analysis has the greatest value for R^2,
- Data from trend analysis for the planned period of March 2010 by July 2010. show the projected growth of factor of safety,
- values of the factor of safety for the treated period with trend analysis, ranging from 1.305 to 2.345, which means proper prediction for the stabilization of slopes,
- values from trend analysis in a relatively small part are overlap with the actual conditions, obtained by direct analysis of the stability of slopes in blocks.

Basically, there is no need to take special measures to stabilize the blocks for treated period. However, because the small value of the coefficient of correlation R^2, similar like a transitional model , there should be more cautious in accepting this information .

After processing the data in Table 17, as well as their statistical analysis was performed following table 5.

Table 5. Input table by method of Spencer for section 49 – 49’

Month	x	F_s	y			
			P(x)	P(x²)	P(x³)	ln(x)
April 2009	4	1,105	1,188	1,184	1,175	1,175
May 2009	5	1,290	1,201	1,200	1,206	1,198
June 2009	6	1,359	1,214	1,216	1,229	1,218
July 2009	7	1,105	1,227	1,231	1,247	1,235
August 2009	8	1,105	1,240	1,246	1,261	1,249
October 2009	10	1,422	1,266	1,273	1,290	1,273
January 2010	13	1,208	1,304	1,309	1,369	1,301
February 2010	14	1,362	1,317	1,320	1,414	1,309
March 2010	15	1,473	1,330	1,330	1,473	1,316
April 2010	16	1,548	1,343	1,340	1,548	1,323
May 2010	17	1,642	1,356	1,349	1,642	1,330
June 2010	18	1,756	1,369	1,358	1,756	1,336
July 2010	19	1,894	1,382	1,366	1,894	1,341

Considering that was analyzed period from April 2009 until February 2010 the input period was 11 months. Trend analysis has effect only if maded for up to ½ of treated, it means that in this case it goes up to the next 5,5 months, was adopted in the analysis period for the next 5 months.

3.1.6. Rating of obtained analytical dependencies according to the value of R^2

According to the ranking in Table 6, we get the conclusion that polynomial from 3 degree (cubic) regression analysis has the maximum value for R^2, or R^2 = 0.1345. Although this value is very low (R^2 <0.3), can not conclude a "more" analytical dependence between the projected factor of safety and time.

However, this regression analysis is adopted as a trend analysis to assess the stability of slopes of the blocks of this section.

3.1.7. Calculation of values for y = f (x) for values of x from 4 to 19

Based on analytical expressions for regression analysis was done calculating of the values for y = f (x) for values of x from 4 to 19. After that is received data given in Table 5, and from them is made Figure 5.

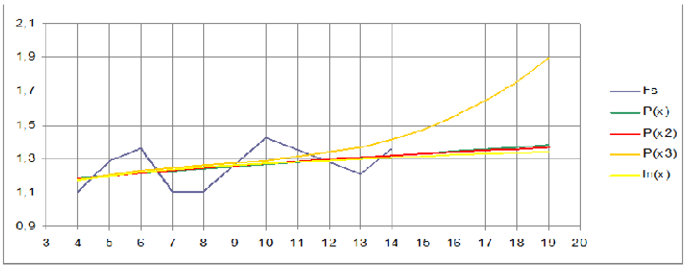

Figure 5. Trend analyses for Spencer Method

According to the diagram of the Figure 5 (and Table 5) can ascertain the following conclusions:

- three regression analysis have the same trend of slight increase, but only is different polynomial regression analysis from 3 degrees has a faster increasing trend, especially in the last two months of research, i.e. June and July in 2010,
- polynomial from 3 degree (cubic) regression analysis has the greatest value for R^2,
- data from trend analysis for the planned period of March 2010 by July 2010. show the projected growth of factor of safety,
- values of the factor of safety for the treated period with trend analysis, ranging from 1.473 to 1.894, which means proper prediction for the stabilization of slopes,
- values from trend analysis in a relatively small part are overlap with the actual conditions, obtained by direct analysis of the stability of slopes in blocks.

Basically, there is no need to take special measures to stabilize the blocks for treated period. However, because the small value of the coefficient of correlation R^2, similar like a transitional model , there should be more cautious in accepting this information .

4. DISCUSSION

The analysis of sections shows that there is a possibility of determination, ie prediction of the coefficient of reliability for the next five to six months, and if compare the predicted with real coefficient of safety, it comes to accuracy and up to 90%, which is a very high percentage.

This proves that the purpose of this paper is justified, because tis get results that can be used in the manufacturing process.

Of all the reported information, with technology for development in open pit mine “Suvodol” for every six months, can get results for the development of the mine, i.e. to avoid unsafe situations and different activities, thus creating conditions for much safer operation of the mine.

From the general cross section of all analyzed sections by different methods for determining the coefficients of reliability are out the following information which may be subject and topic of further discussion.

General, section 49-49’ , it can be concluded that with the performed trend analysis was get information that working slopes of the blocks in this section at the time of the 5 months were basically stable.

By any analysis which is made is get results for predicted coefficients of reliability were are relatively with tendency of growth, and it is a sign that it is necessary to forecast any special measures and procedures for stabilization of the section.

From the elaborations we can concluded that there is a great field for further examination and monitoring of all movements of the coefficient of reliability. Further analysis would contribute for new knowledge and information that could be used in different situations of working of the mine ”Suvodol”.

5. CONCLUSSIONS

The results in the paper gives a new scientific contribution to the assessment of the stability of slopes and their prediction in the future.

The elaborated models for assess the stability of slopes, using trend analysis - regression analysis provides an opportunity for defining new approaches of models for analyzing and predicting the stability of slopes of the blocks.

In this paper was performed a complete analysis on 8 characteristic sections of which, according to the volume of available data, was selected 1 and that was 49-49'.

It was used a number of information from monthly reports for geotechnical stability of blocks from the period of May 2009 until April 2010. With four regression analysis: linear, polynomials of second and third degree and logarithmic obtained analytical expressions of the stability factor in a function of time.

It is given appropriate tabular and graphs from these functions, and separately for each section, i.e. each analyzed method for assessing the stability of slopes (Method of lamella, the method of Bishop, Janbu method and the method of Spencer), separately. So, were used for 3 sections 4 methods for assessment of 4 different regression analysis, i.e., a total of 48 analysis. The following conclusions are noted:

- according to trend analysis section 49-49 '', will be stable in the planned period of time in the next 5 months. These estimates coincide with the real (obtained from the relevant reports) after the expiry of a period;
- analysis of the model 49-49' with 9 input data give a lot more realistic data from the regression analysis. Is given values of the R^2 much bigger than those gated with regression analysis of sections P09 - P09' and 53-53', which are processed by 5 arrays of input data. This indicates that to obtain more realistic trend analysis is necessary at the entrance to include a larger number of trials of a longer period of time;
- with the tests made with regression analysis, is come to the conclusion that the time forecast using trend analysis, should be as short as possible, even less than the allowed half of the input period. This is especially apparent in section 53-53' where 5 trend analysis for July 2010 deviate much from the real anticipated. Cells in the tables are marked in red.
- Overall, stability in the open pit mine, "Suvodol" in the period for which data were taken for analysis, to the period to which provides trend analysis, is the coefficient of stability almost all accounts under one, and month to month, even a slight improvement over 1.3, i.e. 40% increase. This trend matches with the trend analysis done in this paper, especially in section 49-49';
- from a practical point, the situation on the ground in this period is very changed, that stabilizes all major landslides that were active in that time, except some local cracks and separate movements of the material;
- Generally, in mine "Suvodol" there is no report of the geological service for activity on the entire deposit;
- measures and monthly plans for work that were in function for stabilize the situation in the open pit mine "Suvodol" give results, so we came to a situation were we can talk about relaxation as regards the stability of slopes in general;
- we know that every mine is living matter, because the situation in the mine is changing every day, that requires continuous monitoring, bringing and taking series of measures and actions to stabilize the situation and all events related to the stability of the working slopes;
- in every surface mine must conduct regular analysis, for existing and planned events around the stability of working slopes, and with that is make continuous monitoring, prediction of risk situations and resolve them quickly;
- When we devote sufficient attention to these problems and time we will take measures and actions for their prevention and elimination, there is little possibility to come to the destabilization of terrain and slopes; this means, that every mine has to invest in further training to address problems with the stability of the working slopes.

As suggestions for further research can be stated:

- Using sophisticated methods to assess the stability of slopes, especially through the use of finite methods of elements. Also, using methods for making spatial analysis, analyzing and drawing diagrams for voltage condition in space, and using analysis for the time;

- Multiple analysis and evaluation, which involves using personal methods for assessing the stability of the same problem and making collective reliable and timely decisions. Also, using reliable mathematical apparatus, ie regression analysis with higher values of coefficient of correlation;
- implementation of modern measures and procedures for stabilize the working slopes.

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